4. Required Modeling Assumptions and Algorithms

Most of the modeling assumptions and algorithms about building operation and climate are either fixed or restricted when an ACM is used for compliance.

All approved ACMs shall include and automatically use all the appropriate fixed and restricted inputs and calculation methods with no special entry required by the user. Users may not override the fixed inputs when the ACM is used for compliance calculations, nor are users allowed to go beyond the limitations of the restricted assumptions.

The fixed and restricted modeling assumptions apply to both the *Standard Design* run and to the *Proposed Design* run. The *standard* fixed and restricted modeling assumptions always apply to the *Standard Design* run and are the *default* for the *Proposed Design*. In some cases, the CEC has approved *alternate* fixed and restricted modeling assumptions that may be used in the *Proposed Design* run. When the assumptions differ between the *Standard Design* and the *Proposed Design*, this is called to the attention of the reader in this chapter. The alternate modeling assumptions may only be used when the *Proposed Design* run has a special building feature (e.g. zonal control) that is recognized for credit, and the ACM has been approved with this modeling capability. The modeling of such building features for compliance purposes shall always be documented in the *Special Features and Modeling Assumptions* listings on the Certificate of Compliance.

While this manual describes the algorithms and calculation methods used by the reference method, an ACM may use alternative algorithms to calculate the energy use of low-rise residential buildings provided that the algorithms are used consistently for the *Standard Design* and the *Proposed Design* and provided that the ACM passes the applicable tests described in Chapters 5 and 6.

4.1 General Modeling Assumptions

4.1.1 Weather Data

All ACMs shall use standard hourly weather data for compliance runs. The same hourly weather data and weather data format shall be used for both the *Standard Design* and the *Proposed Design* calculations.

ACM Joint Appendix II contains information about how to obtain the official CEC weather data. There are 16 climate zones with a complete year of 8,760 hourly weather records. Each climate zone is represented by a particular city.

Time Dependent Valuation (TDV) energy is the parameter used to compare the energy consumption of proposed designs to energy budgets. TDV replaces the source energy multipliers of one for natural gas and 3 for electric. TDV is explained in ACM Joint Appendix III in more detail.

4.1.2 Ground Reflectivity

ACMs shall assume that the ground surrounding residential buildings has a reflectivity of 20 percent in both summer and winter. This applies to both the *Standard Design* and *Proposed Design*.

4.1.3 Thermostats

The *standard* thermostat settings are shown in Table R4-1 below. The values for the “Whole House” apply to the *Standard Design* run and are the default for the *Proposed Design* run. See the explanation later in this section regarding the values for Zonal Control.

Table R4-1 – Hourly Thermostat Set Points

	Whole House		Zonal Control Living Areas		Zonal Control Sleeping Areas		
Hour	Heating	Cooling	Heating	Cooling	Heating	Cooling	Venting
1	65	78	65	83	65	78	Off
2	65	78	65	83	65	78	Off
3	65	78	65	83	65	78	Off
4	65	78	65	83	65	78	Off
5	65	78	65	83	65	78	Off
6	65	78	65	83	65	78	68
7	65	78	65	83	65	78	68
8	68	83	68	83	68	83	68
9	68	83	68	83	65	83	68
10	68	83	68	83	65	83	68
11	68	83	68	83	65	83	68
12	68	83	68	83	65	83	68
13	68	83	68	83	65	83	68
14	68	82	68	82	65	83	68
15	68	81	68	81	65	83	68
16	68	80	68	80	65	83	68
17	68	79	68	79	65	83	68
18	68	78	68	78	65	83	68
19	68	78	68	78	65	83	68
20	68	78	68	78	65	83	68
21	68	78	68	78	65	83	68
22	68	78	68	78	68	78	68
23	68	78	68	78	68	78	68
24	65	78	65	83	65	78	Off

Determining Heating Mode vs. Cooling Mode. When the building is in the heating mode, the heating setpoints for each hour are set to the “Heating” values in Table R4-1, the cooling setpoint is set to a constant 78°F and the ventilation setpoint is set to a constant 77°F. When the building is in the cooling mode, the “Cooling” values are used. The heating setpoint is set to a constant 60°F, and the cooling and venting setpoints are set to the values in Table R4-1.

The state of the building's conditioning mode is dependent upon the outdoor temperature averaged over hours 1 through 24 of day 8 through day 2 prior to the current day (e.g., if the current day is June 21, the mode is based on the average temperature for June 13 through 20). The ACM shall calculate and update daily this 7-day running average of outdoor air temperature. When this running average temperature is equal to or less than 60°F the building shall be set in a heating mode and all the thermostat setpoints for the heating mode shall apply. When the running average is greater than 60°F the building shall be set to be in a cooling mode and the cooling mode setpoints shall apply.

Zonal Control: An optional capability, described in Chapter 6, allows alternative thermostat schedules to be used for the *Proposed Design* run when the HVAC system meets the requirements for zonal control. With zonal control, the building is divided into sleeping and living areas and a separate schedule is used for each area. If the user selects this option the ACM shall use the appropriate alternative schedules based on the user’s designations for sleeping and living zones and shall automatically report the use of this optional capability in the *Special*

Features and Modeling Assumptions listings in the CF1-R. The setpoints for zonal control are also shown in Table R4-1.

Setback Thermostat Exceptions. Certain types of heating and/or cooling equipment are excepted from the mandatory requirement for setback thermostats, including wall furnaces and through-the-wall heat pumps. If setback thermostats are not installed, then the ACM shall model the *Proposed Design* with the standard thermostat schedule, except that the heating mode setback setpoint shall be 66°F. In cases where setback thermostats are not mandatory but nonetheless are installed by the builder, the ACM shall model the *Proposed Design* using the standard heating setback setpoint of 65°F. The *Standard Design* always assumes the setback schedule shown in Table R4-1.

4.1.4 Internal Gains

Basic Allocation

Internal gain from lights, appliances, people and other sources shall be set to 20,000 Btu/day for each dwelling unit plus 15 Btu/day for each square foot of conditioned floor area (CFA) as shown in Equation R4-1.

Equation R4-1
$$IntGain_{total} = (20{,}000 \times N) + \left(15 \times \sum_{i=1}^{N} CFA_i\right)$$

Where

N= Number of dwelling units

CFA_i= Conditioned Floor Area of i^{th} dwelling unit

Zonal Control

For zonal control, an optional modeling capability, the internal gains are split between the living areas and the sleeping areas as indicated in the following equations. The 20,000 Btu/day fixed component is assigned 100% to the living areas and the 15 Btu/ft² component is allocated according to floor area. See Equation R4-2 and Equation R4-3.

Equation R4-2
$$IntGain_{Living} = 15 \times CFA_{Living}$$

Equation R4-3
$$IntGain_{Sleeping} = 15 \times CFA_{Sleeping}$$

Additions

For addition-alone compliance (single-zone), the internal gains are apportioned according to the fractional conditioned floor area, referred to as the Fractional Dwelling Unit (FDU). For zone j, the internal gain is determined by Equation R4-4.

Equation R4-4
$$IntGainZone_j = IntGain_{tot} \times FDU_j$$

where

FDU_j = Fractional Dwelling Unit of j^{th} zone, calculated from Equation R4-5

Equation R4-5

$$FDU_j = \frac{CFA_j}{CFA_{total}}$$

Building additions may be modeled in conjunction with the existing dwelling or modeled separately (see Chapter 6). When modeled together the number of dwelling units for the proposed dwelling ($NDU_{proposed}$) remains equal to the number of dwelling units for the existing structure ($NDU_{existing}$), while the conditioned floor area ($CFA_{proposed}$) is increased to include the contribution of the addition ($CFA_{addition}$). When modeled separately, the internal gain of the addition ($IntGain_{addition}$)is based on the value of the addition's fractional dwelling unit ($FDU_{addition}$), as expressed in Equation R4-6 and Equation R4-7.

Equation R4-6

$$IntGain_{addition} = IntGain_{total} \times FDU_{addition}$$

Equation R4-7

$$FDU_{addition} = \frac{CFA_{addition}}{CFA_{existing} + CFA_{addition}}$$

Hourly Schedules

The standard hourly internal gain schedule is shown in Table R4-2. “Hour one” is between midnight and 1:00 am. The whole building schedule shall always be used for the *Standard Design* run. The whole building is also used for the *Proposed Design* unless the *Proposed Design* has zonal control. For zonal control, the Living Areas schedule is used for the living areas and the Sleeping Areas schedule is used for sleeping areas.

Table R4-2 – Hourly Internal Gain Schedules

	Percent of Daily Total Internal Gains (%)		
Hour	Whole House	Living Areas	Sleeping Areas
1	2.40	1.61	4.38
2	2.20	1.48	4.02
3	2.10	1.14	4.50
4	2.10	1.13	4.50
5	2.10	1.21	4.32
6	2.60	1.46	5.46
7	3.80	2.77	6.39
8	5.90	5.30	7.40
9	5.60	6.33	3.76
10	6.00	6.86	3.85
11	5.90	6.38	4.70
12	4.60	5.00	3.61
13	4.50	4.84	3.65
14	3.00	3.15	2.63
15	2.80	2.94	2.46
16	3.10	3.41	2.32
17	5.70	6.19	4.47
18	6.40	7.18	4.45
19	6.40	7.24	4.29
20	5.20	5.96	3.30
21	5.00	5.49	3.75
22	5.50	6.20	3.75
23	4.40	4.38	4.45
24	2.70	2.35	3.59
Total	100.00	100.00	100.00

Seasonal Adjustments

Daily internal gain shall be modified each month according to the multipliers shown in Table R4-3. These multipliers are derived from the number of daylight hours for each month.

Table R4-3 – Seasonal Internal Gain Multipliers

Month	Multiplier	Month	Multiplier	Month	Multiplier
Jan	1.19	May	0.84	Sep	0.98
Feb	1.11	Jun	0.80	Oct	1.07
Mar	1.02	Jul	0.82	Nov	1.16
Apr	0.93	Aug	0.88	Dec	1.21

4.2 Heat Gains and Losses Through Opaque Surfaces

4.2.1 Radiant Barriers

Algorithm

The benefits of radiant barriers are modeled in two ways. First, the ceiling U-factor is modified for each season (heating mode and cooling mode) to account for reduced heat gain (attics are not modeled as separate unconditioned thermal zones in residential ACMs). Second, the seasonal temperatures for attics are lower with radiant barriers, which results in better HVAC distribution efficiency for ducts located in the attic. See the algorithms for HVAC air distribution ducts for more details.

When the building is in a heating mode, (see Section 4.1.3), Equation R4-8 provides the U-factor modifier due to the presence of a radiant barrier. When the building is in a cooling mode, Equation R4-9 is used. To determine the U-factor for a ceiling with a radiant barrier, multiply the U-factor of the ceiling assembly located beneath a radiant barrier times the U-factor modifier. These modifiers may only be used for installed insulation greater than R-8, otherwise the modifer is 1.00.

Equation R4-8
$$UfacMod_{heating} = (-11.404 \text{ x } U^2) + (0.21737 \text{ x } U) + 0.92661$$

Equation R4-9
$$UfacMod_{cooling} = (-58.511 \text{ x } U^2) + (3.22249 \text{ x } U) + 0.64768$$

Eligibility Criteria

Radiant barriers shall meet specific eligibility and installation criteria to be modeled by any ACM and receive energy credit for compliance with the energy efficiency standards for low-rise residential buildings.

- The emittance of the radiant barrier shall be less than or equal to 0.05 as tested in accordance with ASTM C-1371 or ASTM E408.
- Installation shall conform to ASTM C1158 (*Standard Practice for Installation and Use of Radiant Barrier Systems (RBS) in Building Construction*), ASTM C727 (*Standard Practice for Installation and Use of Reflective Insulation in Building Constructions*), ASTM C1313 (*Standard Specification for Sheet Radiant Barriers for Building Construction Applications*), and ASTM C1224 (*Standard Specification for Reflective Insulation for Building Applications*), and the radiant barrier shall be securely installed in a permanent manner with the shiny side facing down toward the interior of the building (ceiling or attic floor). Moreover, radiant barriers shall be installed at the top chords of the roof truss/rafters in ***any*** of the following methods:

  1. Draped over the truss/rafter (the top chords) before the upper roof decking is installed.
  2. Spanning between the truss/rafters (top chords) and secured (stapled) to each side.
  3. Secured (stapled) to the bottom surface of the truss/rafter (top chord). A minimum air space shall be maintained between the top surface of the radiant barrier and roof decking of not less than 1.5 inches at the center of the truss/rafter span.
  4. Attached [laminated] directly to the underside of the roof decking. The radiant barrier shall be laminated and perforated by the manufacturer to allow moisture/vapor transfer through the roof deck.

  In addition, the radiant barrier shall be installed to cover all gable end walls and other vertical surfaces in the attic.

- The attic shall be ventilated to:

  1. Conform to the radiant barrier manufacturer's instructions.

2. Provide a minimum free ventilation area of not less than one square foot of vent area for each 150 square feet of attic floor area.

3. Provide no less than 30 percent upper vents.

Ridge vents or gable end vents are recommended to achieve the best performance. The material should be cut to allow for full airflow to the venting.

- The radiant barrier (except for radiant barriers laminated directly to the roof deck) shall be installed to have a minimum gap of 3.5 inches between the bottom of the radiant barrier and the top of the ceiling insulation to allow ventilation air to flow between the roof decking and the top surface of the radiant barrier have a minimum of six (6) inches (measured horizontally) left at the roof peak to allow hot air to escape from the air space between the roof decking and the top surface of the radiant barrier.
- When installed in enclosed rafter spaces where ceilings are applied directly to the underside of roof rafters, a minimum air space of 1 inch shall be provided between the radiant barrier and the top of the ceiling insulation, and ventilation shall be provided for every rafter space. Vents shall be provided at both the upper and lower ends of the enclosed rafter space.
- The product shall meet all requirements for California certified insulation materials [radiant barriers] of the Department of Consumer Affairs, Bureau of Home Furnishings and Thermal Insulation, as specified by CCR, Title 24, Part 12, Chapter 12-13, Standards for Insulating Material.
- The use of a radiant barrier shall be listed in the *Special Features and Modeling Assumptions* listings of the CF-1R and described in detail in the ACM Compliance Supplement.

4.2.2 Cool Roofs

Algorithm

Cool roofs are modeled to have an impact equal to the cooling savings for radiant barriers. The calculations for cool roofs are the same as radiant barriers, except that $UfacMod_{heating}$ (see Equation R4-8) is assigned a value of 1.00. In the event that both a cool roof and radiant barrier are specified, there is no credit for the cool roof.

Eligibility Criteria

Cool roofs shall meet specific eligibility and installation criteria to receive credit for compliance. The solar reflectance shall be 0.4 or higher for tile roofs or 0.7 or higher for other roof materials; and the emittance shall be 0.75 or higher. Liquid applied cool roof products shall meet the requirements of Section 118(i)3 of the standards. All products qualifying for this credit shall be rated and labeled by the Cool Roof Rating Council in accord with Section 10-113 of the standards. The use of a cool roof shall be listed in the *Special Features and Modeling Assumptions* listings of the CF-1R and described in detail in the ACM Compliance Supplement.

4.2.3 R-Value/U-factor Determinations

Thermal resistances (R-values) and thermal transmittance values (U-factors) shall be determined from ACM Joint Appendix IV. Standard framed (wood and metal) walls with studs 16 in. on center shall be modeled to have 25% framing, and standard framed walls with studs located at 24 in. centers shall be modeled to have 22% framing.

Degree of Precision: The total R-value shall be entered, stored, displayed, and calculated to at least three significant figures, or, alternatively to two decimal places, and the total U-factor to two significant figures or three decimal places whichever is more precise.

Data from ACM Joint Appendix IV shall be used in compliance calculations unless the Energy Commission approves alternate values through the exceptional methods process. Appendix IV also includes pre-calculated assemblies that meet the default U-factors using a combination of batt and rigid insulation. Steel framing assemblies are also included. Appendix IV has R-values for common materials; information on a variety of masonry wall assemblies; and other data useful in determining the U-factor of an assembly.

4.2.4 Insulation Installation Quality

Compliance credit is available for low-rise residential buildings if field verification is performed to ensure that quality insulation and air barrier installation procedures are followed (see Appendix RH). All newly insulated opaque surfaces in a building must be field verified to receive this credit. Compliance reports and user interfaces shall identify the building as having either *Standard* or *Improved* insulation installation quality. As discussed in Chapter 3, the *Standard Design* shall have standard insulation installation quality. Approved ACMs must be able to model both *Standard* and *Improved* insulation installation quality (see Table R4-4).

Table R4-4 – Modeling Rules for insulation installation Quality

		insulation installation Quality	
Component	Mode	Standard	Improved
Walls	Both	Increase heat gains and losses by 19%, i.e., multiply all wall U-factors by 1.19.	Increase heat gains and losses by 5%, i.e., multiply all wall U-factors by 1.05.
Ceilings/Roofs	Heating	Add 0.02 times the area to the UA of each ceiling surface i.e., add 0.02 to the U-factor.	Add 0.01 times the area to the UA of each ceiling surface i.e., add 0.01 to the U-factor.
	Cooling	Add 0.005 times the area to the UA of each ceiling surface i.e., add 0.005 to the U-factor.	Add 0.002 times the area to the UA of each ceiling surface i.e., add 0.002 to the U-factor.

When credit is taken for Improved insulation installation quality, the *Field Verification and Diagnostic Testing* section of the CF-1R shall show that field verification is required (see Chapter 2) and the Installation Certificate (CF-6R) and the Field Verification and Diagnostic Testing Certificate (CF-4R) must be completed and signed by the installer and HERS Rater, respectively.

4.2.5 Perimeters of Slab Floors and Carpeted Slabs

For *Standard and Proposed Designs* all ACMs shall use slab edge F2 values assuming that 20% of the slab floor perimeter is exposed to the conditioned air and 80% of the slab floor perimeter is carpeted or covered with an R-2 insulating layer between the slab and the conditioned air. See ACM Joint Appendix IV.

The monthly ground temperatures shown in Table R4-5 shall be used as the exterior temperature when calculating slab edge heat loss.

Table R4-5 – Monthly and Annual Average Ground Temperatures

Climate Zone	J	F	M	A	M	J	J	A	S	O	N	D	Annual Average
	Month												
1	52.2	51.5	51.4	51.8	53.1	54.5	55.6	56.4	56.4	55.8	54.7	53.4	53.9
2	53.3	51.5	51.4	52.2	55.6	58.9	61.8	63.6	63.8	62.3	59.5	56.3	57.5
3	55.1	54.1	54.0	54.5	56.5	58.5	60.3	61.4	61.5	60.6	58.9	56.9	57.7
4	55.5	54.0	53.9	54.6	57.5	60.3	62.8	64.3	64.5	63.2	60.8	58.0	59.1
5	55.7	54.8	54.7	55.2	56.9	58.7	60.2	61.1	61.2	60.4	59.0	57.3	57.9
6	59.1	58.1	58.0	58.5	60.4	62.4	64.0	65.1	65.2	64.3	62.7	60.8	61.6
7	60.1	59.1	59.0	59.5	61.5	63.4	65.2	66.2	66.3	65.5	63.8	61.9	62.6
8	60.0	58.8	58.7	59.2	61.6	63.9	66.0	67.3	67.4	66.3	64.3	62.1	63.0
9	60.5	59.1	59.0	59.7	62.2	64.8	67.1	68.5	68.6	67.5	65.3	62.8	63.8
10	59.4	57.6	57.4	58.3	61.8	65.2	68.2	70.1	70.2	68.7	65.8	62.4	63.8
11	54.9	52.4	52.2	53.4	58.2	63.0	67.2	69.8	70.0	67.9	63.8	59.2	61.0
12	54.6	52.5	52.3	53.3	57.3	61.3	64.8	67.0	67.2	65.4	62.0	58.1	59.7
13	57.5	54.7	54.5	55.8	61.0	66.2	70.6	73.5	73.7	71.4	67.0	62.0	64.0
14	54.2	51.2	51.0	52.4	58.2	63.9	68.8	72.0	72.2	69.7	64.8	59.3	61.5
15	66.8	64.0	63.8	65.1	70.4	75.8	80.4	83.3	83.6	81.2	76.7	71.5	73.6
16	44.4	41.8	41.6	42.8	47.7	52.6	56.8	59.5	59.7	57.5	53.4	48.7	50.5

4.2.6 Basement Modeling - Basement Walls and Floors

Below grade walls shall be modeled with no solar gains, i.e., absorptivity is zero. Below grade walls are modeled with three exterior conditions depending on whether the depth is shallow, medium, or deep. The temperature of the earth depends on the depth of the wall and is given in Table R4-6. Thermal resistance also shall be increased to account for earth near the construction (see Table R4-6).

Table R4-6 – Earth Temperatures for Modeling Basement Walls and Floors

Class	Depth	Assumed Temperature of the Earth	Thermal Resistance of Earth
Shallow Depth Walls	Up to 2 ft	Average air temperature for hours 1 through 24 of the 7 days beginning 8 days prior to the current day (days -8 through -2).	A thermal resistance with an R-value of 1.57 (hr.ft^2.^{o}F/Btu) is added to the outside of the below grade wall.
Medium Depth Walls	2+ to 6 ft	Exterior earth temperature is assumed to be the monthly average temperature from Table R4-5.	A thermal resistance with an R-value of 7.28 (hr.ft2.^{o}F/Btu) is added to the outside of the below grade wall.
Deep Walls	More than 6 ft	Exterior earth temperature is used which is typical of deep ground. Use the annual average value from Table R4-5.	A thermal resistance with an R-value of 13.7 (hr.ft2.^{o}F/Btu) is added to the outside of the below grade wall.
Basement Floors	Any	Exterior earth temperature is used which is typical of deep ground. Use the annual average value from Table R4-5.	A thermal resistance with an R-value of 17.6 (hr.ft2.^{o}F/Btu) is added to the bottom of the basement floor.

4.3 Heat Gains and Losses through Fenestration

4.3.1 Fenestration Products

Information concerning fenestration products, specifically the default table for fenestration U-factors and the default table for fenestration SHGC values, is included in Section 116 of Title 24, Part 6.

4.3.2 Solar Gain

Solar gain through glazing shall be calculated using the methods documented in the *Algorithms and Assumptions Report, 1988*. However, solar gain through windows is reduced to 72 percent of the full solar gain and a algorithm is used to calculate the transmitted solar gain as a function of the angle of incidence on the glazing. The 0.72 multiplier is intended to compensate for exterior shading from landscaping, terrain, and adjacent buildings, as well as dirt and other window obstructions.

The equations used to calculate the solar heat gain through windows as a function of the angle of incidence are given below in the form of two multipliers: - G_{dir} - the ratio of the solar heat gain to the space relative to direct beam insolation at normal incidence, and G_{dif} - the ratio of solar heat gain to the space relative to the diffuse insolation on a horizontal surface. These ratios are unitless.

Equation R4-10 $$G_{dir} = SHGC_{fen} * Area * \left[fsunlit * CosI * P(CosI) + GrndFac\right]$$

and

Equation R4-11 $$G_{dif} = SHGC_{fen} * Area * DMSHGC * \left(vfSky + vfGrnd * GrndRf\right)$$

where

Equation R4-12 $$P(CosI) = C1 * CosI + C2 * Cos^2 I + C3 * Cos^3 I + C4 * Cos^4 I$$

Equation R4-13 $$GrndFac = vfGrnd \times CosG \times GrndRf \times DMSHGC$$

$SHGC_{fen}$ =	Fenestration Solar Heat Gain Coefficient at normal beam incidence - primary user input [unitless]
CosI =	The cosine of the angle of incidence of the direct beam insolation on the window. [unitless]
CosG =	The cosine of the angle of incidence of the direct beam insolation on the ground. [unitless]
DMSHGC =	Diffuse Multiplier for Solar Heat Gain Coefficient [unitless]
fsunlit =	Fraction of the window sunlit by direct beam at this hour [unitless]
C1, ...,C4 =	Polynomial coefficients for angular dependence (cosine of the angle of incidence) of solar heat gain - see Table R4-7.
vfSky =	View factor of window to sky [unitless]
vfGrnd =	View factor from window to ground [unitless]
GrndRf =	Ground Reflectance [unitless] = 0.20

Table R4-7 – Polynomial Coefficients for Angular Dependence

Glazing Type:	Single Pane (1 light)	More Than One Pane (2 or more lites)
$SHGC_{fen}$	0.860	0.695
C1	3.549794	1.881643
C2	-4.597536	1.014431
C3	2.432124	-4.009235-
C4	-0.384382	2.113160
DMSHGC	0.905814	0.828777

4.3.3 Interior and Exterior Shading

Draperies are assumed to be closed only for hours when the air conditioner operates. To approximate this affect during transitions between periods of operation and non-operation, ACMs may assume that the internal device remains closed for the hour following an hour of air conditioner operation. As soon as that hour passes, the internal shading device shall be opened unless the air conditioner continues to run. The internal device shall be either totally open or totally closed for any given hour.

External sunscreens are assumed to be in place all year, whether the building is in a heating or cooling mode.

The shading effects of overhangs, side fins and other fixed shading devices are determined hourly, based on the altitude and azimuth of the sun for that hour, the orientation of the fenestration, and the relative geometry of the fenestration and the fixed shading devices.

The standard assumptions for operation of interior shading devices and sunscreens shall apply to both the *Standard Design* and the *Proposed Design*.

4.3.4 Solar Heat Gain Coefficients

ACMs use two solar heat gain coefficient values: "$SHGC_{open}$ " and "$SHGC_{closed}$." "$SHGC_{open}$ " applies when the air conditioner is not in operation (off) and "$SHGC_{closed}$ " applies when the air conditioner is in operation. The ACM user shall not be allowed to enter values for $SHGC_{open}$ and $SHGC_{closed}$. The ACM shall automatically determine these values from the user's choices of exterior shading devices and from the assumption that vertical glazing has a drapery and non-vertical (skylight) glazing has no interior shading device.

There are a limited set of shading devices with fixed prescribed characteristics that are modeled in the performance approach. These devices and their associated fixed solar heat gain coefficients are listed in Table R3-5 and Table R3-7.

The formula for combining solar heat gain coefficients is:

Equation R4-14

$$SHGC_{comb} = \left[\left(0.2875 \times SHGC_{max}\right) + 0.75\right] \times SHGC_{min}$$

where

$SHGC_{comb}$ = the combined solar heat gain coefficient for a fenestration component and an attachment in series.

$SHGC_{max}$ = the larger of $SHGC_{fen}$ and $SHGC_{dev}$

$SHGC_{min}$ = the smaller of $SHGC_{fen}$ and $SHGC_{dev}$

where

$SHGC_{fen}$ = the solar heat gain coefficient of the fenestration which includes the window glazing, transparent films and coatings, and the window framing, dividers and muntins,

$SHGC_{dev}$ = the solar heat gain coefficient of the interior or exterior shading device when used with a metal-framed, single pane window.

For $SHGC_{closed}$, the combination SHGC, $SHGC_{fen+int}$, (the combined SHGC for the fenestration and the interior device) is calculated first and then the combination $SHGC_{fen+int+ext}$ is calculated to determine the overall $SHGC_{closed}$. $SHGC_{open}$ is determined from the combination of $SHGC_{fen}$ and $SHGC_{ext}$.

4.4 Thermal Mass

ACMs shall be capable of modeling thermal mass in buildings. Thermal mass has the ability to store heat and thus damp temperature fluctuations in the conditioned space. There are two types of thermal mass, *Light Mass* which reacts very quickly to absorb or release heat, and *Heavy Mass* which reacts more slowly*. Light Mass* is modeled in the same way for both the *Proposed Design* and the *Standard Design*. The modeled mass includes common elements such as framing, furniture, ½ in. gypsum board, and household appliances. Light mass is modeled through an input in the reference program called building heat capacity and is assumed to be fixed at 3.5 Btu/ºF-ft² of conditioned floor area for both the *Proposed Design* and the *Standard Design*. Other values may be used for unconditioned zones (see Chapter 6).

"Heavy" mass includes elements such as concrete slab floors, masonry walls, double gypsum board and other special mass elements. When the *Proposed Design* qualifies as a high mass building then each element of heavy mass is modeled in the *Proposed Design*, otherwise, the *Proposed Design* is modeled with the same heavy thermal mass as the *Standard Design*. See Chapter 3 for details on what qualifies as a high mass building. The default thermal mass for the *Proposed Design* and the fixed thermal mass for the *Standard Design* is based on 20% of the slab floor being exposed and 80% covered with carpet or casework. In addition 5% of the non-slab floor is exposed with a topping of 2 in. of concrete. ACM RB-2005 has procedures for quantifying the value of various types of thermal mass.

Solar Gain Targeting. Solar gains from windows or skylights shall not be targeted to mass elements within the conditioned space of the building. In the reference program, CALRES, all solar gain is targeted to the air or a combined air-and lightweight, high surface area mass node within the building. This modeling assumption is used in both the *Standard Design* run and the *Proposed Design* run, except for sunspaces where the user has flexibility in targeting solar gains subject to certain constraints. Sunspace modeling is an optional capability discussed in Chapter 6.

Unconditioned Sunspaces. For compliance purposes, when glazing surfaces enclose unconditioned spaces, such as sunspaces, the user is allowed to target all but 25% of the solar gains from these surfaces to *Heavy* mass elements located within the unconditioned space. Unassigned solar gain is targeted to the air or the combined air/lightweight mass or to high surface area lightweight mass in the unconditioned space. At least 25% of the solar gain from any sunspace fenestration surface shall be targeted to high surface area lightweight mass and/or the air. At most 60% of the solar gain may be targeted to the slab floor of a sunspace, especially in the summer. For compliance purposes, an ACM shall automatically enforce these limits and inform the user of any attempt to exceed these limits.

4.5 Infiltration and Natural Ventilation

4.5.1 Infiltration/Ventilation

The reference method uses the effective leakage area method for calculating infiltration in conditioned zones. Calculations shall use Shielding Class 4 as defined in the 2001 *ASHRAE Handbook of Fundamentals*.

Default Specific Leakage Area. The default specific leakage area (SLA) is 4.9 for designs with ducted HVAC systems and 3.8 for non-ducted HVAC systems. The default is always used for the *Standard Design*. The *Proposed Design* may use an alternate value, but only with diagnostic testing. The specific leakage area (SLA) is the ratio of the effective leakage area to floor area in consistent units. The value is then increased by 10,000 to make the number more manageable. If the effective leakage area (ELA) is known in inches, then the SLA may be calculated with Equation R4-15.

Equation R4-15 $$SLA = \left(\frac{ELA}{CFA}\right)\left(\frac{ft^2}{144in^2}\right)(10000) = \left(\frac{ELA}{CFA}\right)69.444$$

where

ELA = Effective leakage area in square inches

CFA = Conditioned floor area (ft²)

SLA = Specific leakage area (unitless)

Minimum Outside Air. For both the *Standard Design* and the *Proposed Design*, ACMs shall assume that occupants will open the windows if the air becomes stagnant. When natural ventilation, infiltration, and mechanical ventilation fall below a threshold value of 0.35 air changes per hour (ACH) , the occupants are assumed to open the windows at the beginning of the next hour sufficient to provide a combination of infiltration and ventilation equal to 0.35 ACH for an eight foot high ceiling. The windows are assumed to remain partially open to provide a minimum of 0.35 ACH as long as the previous hour's infiltration and mechanical ventilation rate is below the threshold.

Effective Leakage Area (ELA) Method. The Effective Leakage Area (ELA) method of calculating infiltration for conditioned zones is documented below and in Chapter 26 of the 2001 ASHRAE Handbook of Fundamentals. The ELA for the *Standard Design* and for the default values for the *Proposed Design* (if diagnostic tests are not used), is calculated from Equation R4-15. The energy load on the conditioned space from infiltration heat gains or losses are calculated as follows.

Equation R4-16 $$CFM_{infil} = ELA \times \sqrt{A \times \Delta T_2 + B \times V^2}$$

Equation R4-17 $$CFM_{infil+unbalfan} = \sqrt{CFM_{infil}^2 + MECH_{unbal}^2}$$

Equation R4-18 $$CFM_{infil+totfan} = CFM_{infil+unbalfan} + MECH_{bal}$$

The volumetric airflow (cfm) due to natural ventilation is derived from the natural ventilation cooling for the hour:

Equation R4-19 $$CFM_{natv} = \frac{Q_{natv}}{1.08 \times \Delta T_1}$$

The total ventilation and infiltration (in cfm) including indoor air quality window operation is:

Equation R4-20 $$CFM_{total} = CFM_{natv} + CFM_{infil+totfan} + CFM_{iaq}$$

The value of CFM_{iaq} depends on the sum of CFM_{natv} and $CFM_{infil+totfan}$ from the previous time step:

When

Equation R4-21 $$CFM_{natv} + CFM_{infil+totfan} < \frac{(AFT \times CFA)}{7.5}$$

then

Equation R4-22
$$CFM_{iaq} = \frac{(0.35 \times CFA)}{7.5}$$

otherwise

Equation R4-23
$$CFM_{iaq} = 0.000$$

where

CFA = the total conditioned floor area of the residence

AFT = 0.18 for Climate Zones 2 through 15 inclusive, and;

AFT = 0.25 for Climate Zones 1 and 16.

When the windows are opened they provide an overall ventilation rate equal to 0.35 air changes per hour for a residence of the same floor area but with eight foot high ceilings. CFM_{iaq} simulates the opening of windows to achieve an acceptable indoor air quality by the occupants when ventilation and infiltration from other sources does not provide an adequate quantity of outdoor air to dilute pollutants and refresh the indoor air.

The energy load on the conditioned space from all infiltration and ventilation heat gains or losses is calculated as follows:

Equation R4-24
$$Q_{total} = 1.08 \times CFM_{total} \times \Delta T_1$$

where

Q_{total} = Energy from ventilation and infiltration for current hour (Btu)

CFM_{infil} = Infiltration in cubic feet per minute (cfm)

$CFM_{infil+unbalfan}$ = combined infiltration and unbalanced mechanical ventilation in cubic feet per minute (cfm)

$CFM_{infil+totfan}$ = infiltration plus the balanced and unbalanced mechanical ventilation in cubic feet per minute (cfm)

$MECH_{bal}$ = the balanced mechanical ventilation in cfm. This value is the smaller of the total supply fan cfm and the total exhaust fan cfm.

$MECH_{unbal}$ = the unbalanced mechanical ventilation in cfm. This value is derived from the absolute value of the difference between the total supply fan cfm and the total exhaust fan cfm.

1.08 = conversion factor in (Btu-min)/(hr-ft^3-°F)

ΔT_1 = difference between indoor and outdoor temperature for current hour (°F)

ΔT_2 = difference between indoor and outdoor temperature for previous hour (°F)

A = stack coefficient, (cfm^2/in^4/ F)

B = wind coefficient, (cfm^2/in^4/mph^2)

V = average wind speed for current hour (mph)

ELA = effective leakage area (in^2), measured or calculated using Equation R4-25.

The stack (A) and wind (B) coefficients to be used are shown in Table R4-8.

Table R4-8 – Infiltration Coefficients

Coefficient	*One Floor*	*Two Floors*	*Three Floors*
A (stack)	0.0156	0.0313	0.0471
B (wind) (Shielding Class 4)	0.0039	0.0051	0.0060

The ELA is calculated from the SLA as follows:

Equation R4-25
$$ELA = CFA \times SLA \times \left(\frac{144in^2}{1ft^2}\right) \times \left(\frac{1}{10{,}000}\right)$$

where

CFA = conditioned floor area (ft^2)

SLA = specific leakage area (ft^2/ft^2)

ELA = effective leakage area (in^2)

Alternatively, ELA and SLA may be determined from blower door measurements:

Equation R4-26
$$ELA = 0.055 \times CFM50_H$$

where

$CFM50_H$ = the measured airflow in cubic feet per minute at 50 pascals for the dwelling with air distribution registers unsealed.

Substituting Equation R4-26 into Equation R4-15 gives the relationship of the measured airflow rate to SLA:

Equation R4-27
$$SLA = 3.819 \times \frac{CFM50_H}{CFA}$$

Reduced Infiltration. ACM users may take credit for reduced infiltration (with mechanical ventilation when it is required) for low-rise, single-family dwellings when verified by on-site diagnostic testing. While credit is offered for reduced infiltration, the model also assumes that dwelling occupants will open windows when natural ventilation and infiltration do not provide a minimum of 0.35 ACH.

The Effective Leakage Area (ELA) of the dwelling may be reduced and the algorithm will result in less energy use due to infiltration unless windows are opened for ventilation. Lower ELAs will result in windows being opened more frequently and at some point energy use may increase. Air quality ventilation may also be added and if this ventilation plus infiltration and cooling ventilation provides adequate air exchange, window ventilation will no longer occur or will occur very infrequently. The energy use of both ventilation exhaust fans and ventilation supply fans shall be entered. These ventilation fans are assumed to operate continuously and the energy use of these fans shall be included as energy use in the *Proposed Design*. Both reduced ELA/SLA and ventilation fans are conditions which require field verification or diagnostic testing and shall be reported in the *Field Verification and Diagnostic Testing* listings on the Certificate of Compliance.

Controlled Ventilation Crawl Spaces and Sunspaces. Controlled ventilation crawl spaces (CVC) and sunspaces are modeled using the air changes per hour method. Modeling of CVC's and sunspaces are optional capabilities covered in Chapter 6. All optional capabilities that are used in the *Proposed Design* shall be reported in the *Special Features and Modeling Assumptions* listings on the Certificate of Compliance.

4.5.2 Natural Ventilation

The natural ventilation model is derived from the 2001 ASHRAE Handbook of Fundamentals. The model considers both wind effects and stack effects.

- Wind driven ventilation includes consideration of wind speed, prevailing direction and local obstructions, such as nearby buildings or hills.
- Stack driven ventilation includes consideration of the temperature difference between indoor air and outdoor air and the difference in elevation between the air inlet and the outlet.

For compliance purposes, the air outlet is always assumed to be 180 degrees or on the opposite side of the building from the air inlet and the inlet and outlet areas are assumed to be equal. The default inlet area (= outlet area) is five percent of the total window area.

Effective Ventilation Area (EVA)

Both wind and stack driven ventilation depends linearly on the effective ventilation area (EVA). The EVA is a function of the area of the air inlet and the area of the air outlet. For compliance purposes, the default area of air inlet and outlet are both equal to five per cent of the total window area, i.e., total ventilation area is 10% of the window area. For compliance purposes a different window opening area may be determined from the areas of different window opening types - fixed, sliders, and hinged windows. For compliance purposes, the air inlet and the air outlet are each equal to one-half of the *Free Ventilation Area*.

When the inlet area and outlet area are equal, the EVA is the same, i.e. equal to the inlet area or the outlet area. Hence for compliance purposes the EVA is equal to one-half of the *Free Ventilation Area.*

Stack Driven Ventilation

Stack driven ventilation results when there is an elevation difference between the inlet and the outlet, and when there is a temperature difference between indoor and outdoor conditions. See Equation R4-28.

Equation R4-28 $$CFM_S = 9.4 \times EVA \times EFF_S \times \sqrt{H \times \Delta T}$$

where

CFM_S = Airflow due to stack effects, cfm.

9.4 = Constant.

EVA = Effective ventilation area as discussed above, ft².

EFF_S = Stack effectiveness.

H = Center-to-center height difference between the air inlet and outlet.

ΔT = Indoor to outdoor temperature difference, °F.

For compliance purposes the stack effectiveness shall be set at 1.0. The ACM user shall not be permitted to alter this value.

Wind Driven Ventilation

The general equation for wind driven ventilation is shown below. This equation works in either a direction dependent implementation or a direction independent implementation, as explained later in the text.

Equation R4-29 $$CFM_w = EVA \times 88 \times MPH \times WF \times EFF_o \times EFF_d$$

where

CFM_W = Ventilation due to wind, cfm.

EVA = Effective vent area as discussed above, ft^2.

88 = A constant that converts wind speed in mph to wind speed in feet per minute.

MPH = Wind speed from the weather tape, mph.

WF = A multiplier that reduces local wind speed due to obstructions such as adjacent buildings. This input is fixed at 0.25 for compliance calculations.

EFF_o = Effectiveness of opening used to adjust for the location of the opening in the building, e.g. crawl space vents. This accounts for insect screens and/or other devices that may reduce the effectiveness of the ventilation opening. This input is also used to account for the location of ventilation area, e.g. the exceptional method for two-zone crawl space modeling provides for an alternative input for EFF_o. This input is fixed at 1.0 for compliance calculations other than crawlspace modeling.

EFF_d = Effectiveness that is related to the direction of the wind relative to the inlet surface for each hour. ASHRAE recommends that the effectiveness of the opening, EFF_d, be set to between 0.50 and 0.60 when the wind direction is perpendicular or normal to the inlet and outlet. A value of 0.25 to 0.35 is recommended for diagonal winds. When the wind direction is parallel to the surface of the inlet and outlet, EFF_d should be zero.

For compliance calculations, the orientation of the inlet and outlet is not considered. ACMs shall assume that the wind angle of incidence at 45 degrees on all windows and only the wind speed dependence is maintained. In this case, the product of EFF_o and EFF_d is equal to 0.28 regardless of the direction of the wind.

Combined Wind and Stack Effects

Stack effects and wind effects are calculated separately and added by quadrature, as shown below. This algorithm always adds the absolute value of the forces; that is, wind ventilation never cancels stack ventilation even though in reality this can happen.

Equation R4-30
$$CFM_t = \sqrt{CFM_w^2 + CFM_s^2}$$

where:

CFM_t = Total ventilation rate from both stack and wind effects, cfm.

CFM_W = Ventilation rate from wind effects, cfm.

CFM_S = Ventilation rate from stack effects, cfm.

Determination of Natural Ventilation for Cooling

The value of CFM_t described in Equation R4-30 above gives the maximum potential ventilation when the windows are open. Natural ventilation is available during cooling mode when there is venting shown in Table R4-1. The amount of natural ventilation used by ACMs for natural cooling is the lesser of this maximum potential amount available and the amount needed to drive the interior zone temperature down to the natural cooling setpoint temperature when natural cooling is needed and available. When natural cooling is not needed or is unavailable no natural ventilation is used. ACMs shall assume that natural cooling is needed when the building is in “cooling mode” and when the outside temperature is below the estimated zone temperature and the estimated zone temperature is above the natural cooling setpoint temperature. Only the amount of ventilation required to reduce the zone temperature down to the natural ventilation setpoint temperature is used and the natural ventilation setpoint temperature shall be constrained by the ACM to be greater than the heating setpoint temperature.

Wind Speed and Direction

Wind speed affects the infiltration rate and the natural ventilation rate. The infiltration and ventilation rate in the reference method accounts for local site obstructions. For infiltration in the reference method this is done by using Shielding Class 4 coefficients (see 2001 ASHRAE Fundamentals, Chapter 26) to determine the stack and wind driven infiltration and ventilation. This Shielding Class determination was made on the basis of the description of the Shielding Classes given in the 2001 ASHRAE Fundamentals which reads as follows:

> Heavy shielding; obstructions around most of the perimeter, buildings or trees within 30 feet in most directions; typical suburban shielding.

The reference method, CALRES, adjusts the wind speed used in calculations through a WF of 0.25. See Equation R4-29.

4.6 Heating Systems

ACMs shall use the following inputs and algorithms to calculate heating energy use.

Equation R4-31

$$NetHLoad_{hr} = \frac{HLoad_{hr} \times HDEM_{hr}}{\eta_{seasonal,dist}}$$

where

NetHLoad$_{hr}$ = The net heating load that the heating equipment sees. This accounts for air distribution duct losses. If there are no air distribution ducts then NetHLoad = HLoad$_{hr}$.

HLoad$_{hr}$ = Space heating load for the hour from the ACM simulation, Btu.

$\eta_{seasonal,\ dist}$ = Seasonal distribution system efficiency for the heating season from Equation R4-55.

HDEM$_{hr}$ = Heating duct efficiency multiplier for the hour calculated from Equation R4-65. This value varies with each hour depending on outdoor temperature. A value of 1.00 (no hourly adjustment) is used unless the supply ducts are located in the attic.

4.6.1 Furnaces and Boilers

Once the net heating load is known, heating energy for gas fired equipment is calculated each hour by dividing the net heating load for that hour by the AFUE. There are no hourly adjustments for part load conditions or temperature dependencies.

Equation R4-32

$$FurnFuel_{hr} = \frac{NetHLoad_{hr}}{AFUE_{eff}}$$

where

AFUE$_{Eff}$ = Annual fuel utilization efficiency. This is a constant for the year.

NetLoad$_{hr}$ = The hourly load calculated from Equation R4-31 and using algorithms similar to those described in this chapter.

4.6.2 Heat pump and Electric Furnace

The reference ACM has a heat pump model which takes account of outdoor temperature. The model uses the following inputs.

HSPF = Rated Heating Seasonal Performance Factor

EIR47 = Defaults to 1/(0.4*HSPF)

Cap47 = Rated compressor heating capacity at 47 F. Defaults to rated cooling capacity.

If the heat pump compressor is not large enough to meet the load in the hour, the ACM assumes there is sufficient backup resistance heat. In the case of an electric furnace, the load shall be met entirely by resistance heat. For heat pumps, the ACM shall calculate the hourly heating electricity consumption in kWh using the DOE2.1E heat pump algorithm.

For equipment without an HSPF rating, the HSPF may be calculated as:

Equation R4-33

$$HSPF = (3.2 \times COP) - 2.4$$

4.6.3 Air Distribution Fans

The test method for calculating AFUE ignores electric energy used by air distribution fans and the contribution of the fan motor input to the heating output. With TDV, electric energy shall be calculated separately from gas energy. For forced-air heating systems, ACMs shall calculate fan energy at the rate of 0.005 watt-hours per Btu of heat delivered by the equipment. The vast majority of residential furnaces have the fan motor in the air stream so the heat generated by the motor contributes to heating the house. This effect may be considered in calculating the TDV energy for heating.

4.7 Air Conditioning Systems

Air conditioning systems shall be sized, installed, tested and modeled according to the provisions of this section.

4.7.1 Cooling System Energy

The reference ACM calculates the hourly cooling electricity consumption in kWh using Equation R4-34. In this equation, the energy for the air handler fan and the electric compressor or parasitic power for the outdoor unit of a gas absorption air conditioner are combined. The ACM calculates the hourly cooling gas consumption in therms using Equation 4-35.

Equation R4-34

$$AC_{kWh} = \frac{Fan_{Wh} + Comp_{Wh} + PPC_{Wh}}{1,000}$$

Equation 4-35

$$AC_{therms} = \frac{Absorption_{Btu}}{100,000}$$

where

AC_{kWh}= Air conditioner kWh of electricity consumption for a particular hour of the simulation. This value is calculated for each hour, combined with the TDV multipliers, and summed for the year.

Fan_{Wh}= Fan watt-hours for a particular hour of the simulation. See Equation R4-48.

$Comp_{Wh}$= Compressor watt-hours for a particular hour of the simulation. This is calculated using Equation R4-36.

$PPC_{Wh=}$ Parasitic Power watt-hours for gas absorption air conditioners for a particular hour of the simulation. This is calculated using Equation R4- 44.

AC_{therms}= Air conditioner therms of gas consumption for a particular hour of the simulation. This value is calculated for each hour, combined with the TDV multipliers, and summed for the year.

$Absorption_{Btu}$= Gas consumption in Btu for absorption air conditioners for a particular hour of the simulation. This is calculated using Equation R4-43.

Electric Compressor Systems

The reference method calculates the energy for electrically driven compressors using the algorithms described in this section.

Compressor watt-hours for a particular hour of the simulation shall be calculated using Equation R4-36.

Equation R4-36

$$Comp_{wh} = \frac{CLoad_{hr} \times CDEM_{hr}}{?_{seasonal,dist} \times CE_t} + \frac{Fan_{wh} x3.413}{CE_t}$$

where

$CLoad_{hr}$ = Space sensible cooling load for the hour from the ACM simulation (Btu).

$CDEM_{hr}$ = Cooling Duct Efficiency Multiplier for the hour calculated from Equation R4-65. This value varies with each hour depending on outdoor temperature. A value of 1.00 is used unless the supply ducts are located in the attic.

$\eta_{seasonal, dist}$ = Seasonal distribution system efficiency for the cooling season from Equation R4-54 $?_{dist,seasonal} = 0.98\, DE_{seasonal} \times F_{recov}$.

CE_t = Sensible energy efficiency at a particular outdoor dry bulb temperature. This is calculated using Equation R4-37 below.

Fan_{wh} = Fan watts this hour. This is calculated using Equation R4-48.

Equation R4-37

$$CE_t = EER_t \times (0.88 + 0.00156 \times (DB_t - 95))$$

where

DB_t = Outdoor dry bulb temperature taken from the CEC weather file.

EER_t = Energy efficiency ratio at a particular dry bulb temperature. EER_t is calculated using Equation R4-38 below.

Equation R4-38

When

$DB_t < 82$ ºF	$EER_t = SEER_{nf}$
$82 \le DB_t < 95$	$EER_t = SEER_{nf} + ((DB_t - 82)*(EER_{nf} – SEER_{nf}) / 13)$
$DB_t \ge 95$	$EER_t = EER_{nf} - (DB_t - 95) * 0.12$

where

$SEER_{nf}$ = Seasonal energy efficiency ratio without distribution fan consumption ("nf" = no fans), but adjusted for refrigerant charge and airflow. This is calculated using Equation R4-39.

EER_{nf} = Energy efficiency ratio at ARI conditions without distribution fan consumption ("nf" = no fans), but adjusted for refrigerant charge and airflow. This is calculated using Equation R4-40.

Equation R4-39

$$SEER_{nf} = (1.0452 \times SEER + 0.0115 \times SEER^2 + 0.000251 \times SEER^3) \times F_{txv} \times F_{air} \times F_{size}$$

Equation R4-40

$$EER_{nf} = \left(1.0452 \times EER + 0.0115 \times EER^2 + 0.000251 \times EER^3\right) \times F_{txv} \times F_{air} \times F_{size}$$

where

SEER = Seasonal energy efficiency ratio for the air conditioner. The EER shall be used in lieu of the SEER for equipment not required to be tested for a SEER rating.

EER = Energy efficiency ratio at ARI test conditions, if not input, then values are taken from Equation R4-41.

F_{txv} = The refrigerant charge factor, default = 0.9. For systems with a verified TXV (ACM RI-2005) or verified refrigerant charge (ACM RD-2005), the factor shall be 0.96.

F_{air} = The system airflow factor, default = .925. For systems with airflow verified according to 4.7.4, F_{air} shall be 1.00.

F_{size} = Compressor sizing factor, default = 0.95. For systems sized according to the Maximum Cooling Capacity for ACM Credit (see Section 4.7.2), the factor shall be 1.0.

Equation R4-41

When

SEER <11.5	EER = 10 - (11.5 - SEER) x 0.83
SEER >= 11.5	EER = 10

Gas Absorption Systems

To determine the electric and gas energy use of gas absorption air conditioning systems the algorithms described in this section should be used.

Equation R4-42

$$Absorption_{Btu} = \frac{CLoad_{hr} \times CDEM_{hr}}{?_{seasonal,dist} \times AE_t} + \frac{Fan_{wh} x3.413}{AE_t}$$

Equation R4-43

$$PPC_{wh} = \frac{CLoad_{hr} \times CDEM_{hr}}{?_{seasonal,dist} \times PE_t}$$

where:

$CLoad_{hr}$ = Space sensible cooling load for the hour from the ACM simulation (Btu).

$CDEM_{hr}$ = Cooling Duct Efficiency Multiplier for the hour calculated from Equation R4-65. This value varies with each hour depending on outdoor temperature. A value of 1.00 is used unless the supply ducts are located in the attic.

$\eta_{seasonal, dist}$ = Seasonal distribution system efficiency for the cooling season from Equation R4-54.

AE_t = Sensible energy efficiency of the gas absorption system at a particular outdoor dry bulb temperature. This is calculated Equation R4-44 using below.

PE_t = Sensible energy efficiency of the parasitic power at a particular outdoor dry bulb temperature. This is calculated using Equation R4-45 below.

Fan_{wh} = Fan watts this hour. This is calculated using Equation R4-48.

Equation R4-44 $$AE_t = COP_t \times (0.88 + 0.00156 \times (DB_t - 95))$$

Equation R4-45 $$PE_t = PEER_t \times (0.88 + 0.00156 \times (DB_t - 95))$$

where

DB_t = Outdoor dry bulb temperature taken from the CEC weather file.

COP_t = COP (coefficient of performance for the gas consumption) of the gas absorption system at a particular dry bulb temperature calculated using Equation R4-46.

$PEER_t$ = PEER (parasitic electricity energy efficiency for the gas absorption system) at a particular outdoor dry bulb temperature calculated using Equation R4-48.

Equation R4-46

DB_t < 83 ºF	COP_t = COP82
83 < DB_t < 95	COP_t = COP82 + ((DB_t - 82)*(COP95 - COP82) / 13)
DB_t > 94	COP_t = COP95 - (DB_t - 95) * 0.00586

Equation R4-47

DB_t < 83 ºF	$PEER_t$ = PEER82
83 < DB_t < 95	$PEER_t$ = PEER82 + ((DB_t - 82)*(PEER95 - PEER82) / 13)
DB_t > 94	$PEER_t$ = PEER95 - (DB_t - 95) * 0.00689

where

CAP95= Rated capacity of the gas absorption system, Btuh, input by the compliance user

COP95 = Rated COP of the gas absorption system, input by compliance user

PPC = Parasitic electric energy at rated conditions, W, input by compliance user

COP82 = COP95 * 1.056

PEER95= CAP95 / PPC, Btu / Wh

PEER82= PEER95 * 1.056

Fan Energy for Cooling

While in a cooling mode, the fan energy associated with the air conditioner is calculated separately from the compressor energy according to Equation R4-48. Calculations are performed hourly.

Equation R4-48

$$Fan_{wh} = \frac{FanW/Btu \times CLoad_{hr} \times CDEM_{hr}}{\eta_{seasonal,dist}}$$

where

FanW/Btu = Fan watts per Btu of rated cooling capacity. This defaults to 0.015 W/Btu. The default value shall be used for the Standard design. Alternate FanW/Btu may be used in ACM calculations for the Proposed design if the actual installed fan watts are less than or equal to the simulation value based on measurements certified by the installer and verified by a rater using the procedure in ACM Appendix RE-2005.

$\eta_{seasonal,\ dist}$ = Seasonal distribution system efficiency for the cooling season from Equation R4-54.

4.7.2 Compressor Sizing

The Design Cooling Capacity shall be calculated using the procedure in ACM RF-2005. The Maximum Cooling Capacity for ACM Credit shall be calculated using the procedure in ACM RF-2005. For ACM energy calculations all loads are assumed to be met in the hour they occur regardless of the compressor size.

Correctly sized systems installed so they operate at full capacity are desirable because oversized cooling systems have been shown to result in larger peak electrical demands. Systems which have the combination of verified adequate airflow, sealed and tested new duct systems, and proper charge (or alternatively a TXV) and also meet the requirements for Maximum Cooling Capacity for ACM Credit may take credit in ACM calculations by setting the Fsize factor (see Equation R4-39 and Equation R4-40) to 0.95. For all other systems the Fsize factor shall be set to 1.0.

4.7.3 Cooling System Refrigerant Charge

Proper refrigerant charge is necessary for electrically driven compressor air conditioning systems to operate at full capacity and efficiency. The presence of a thermostatic expansion valve (TXV) mitigates the impact of charge problems. Field measurements indicate that typical California air conditioning systems are installed without proper charge, and for ACM energy calculations, the F_{txv} factor is set to 0.90 to account for the impact of this condition. If the system without a TXV is properly charged or a TXV is installed, certified and verified according to the procedures of ACM RD-2005 the F_{txv} factor may be set to 0.96 for ACM energy calculations. See Equation R4-39 and Equation R4-40. Credit for refrigerant charge is not available for package systems.

4.7.4 Air Handler Airflow

The efficiency of an air conditioning system is affected by airflow across the evaporator coil. Cooling system airflow is specified in cubic feet per minute per ton (cfm/ton) where one ton of capacity is 12,000 Btu/hour at ARI rated conditions. Cooling airflow is the flow achieved under normal air conditioning operation with the cooling coil wet from condensation.

Adequate Airflow Verification

Verifying adequate airflow is required to allow air conditioning systems to operate at their full efficiency and capacity. Credit may be taken for adequate airflow in ACM calculations by setting the F_{air} factor (see Equation R4-39 and Equation R4-40) to 1.0, but airflow shall be tested, certified and verified using the procedures of ACM RE-2005. When an adequate airflow credit is claimed, the duct design, layout, and calculations shall also be submitted to the local enforcement agency and to a certified HERS rater. Without airflow tests, no credit is allowed for ACM energy calculations and the F_{air} multiplier shall be set to 0.925.

The installer shall measure and certify the airflow. The certified HERS rater shall verify the existence of the duct design layout and calculations, verify that the field installation is consistent with this design, and diagnostically test and verify the airflow rate.

Sufficient Flow for Valid Standard Refrigerant Charge Test

Sufficient airflow is also required to ensure that the refrigerant charge procedure in ACM RD-2005 will produce valid results. Verifying sufficient airflow is a prerequisite for the refrigerant charge test. Either the flow measurement procedure or the temperature split test of ACM RD-2005 may be used to demonstrate Sufficient Airflow.

Air Handler Fan Flow

Table R4-9 shows the criteria used for calculations and measurement of airflow for cooling systems. If a flow test is done using the fan only switch on the air handler, the coil will be dry allowing higher airflow, and the Dry Coil criterion shall be used.

Table R4-9 – Airflow Criteria

Note: All airflows are for the fan set at the speed used for air conditioning.

Test and Condition	Cooling airflow (Wet Coil)	Test Flow if Dry Coil
Default Cooling Airflow	300 cfm/ton	N/A
Flow needed for a valid refrigerant charge test	350 cfm/ton (See Note 1)	400 cfm/ton
Adequate Airflow	400 cfm/ton	450 cfm/ton
Note 1. In lieu of airflow measurements, the system can pass the temperature split test documented in ACM RD-2005.		

4.8 Duct Efficiency

The procedures in this section shall be used to calculate the efficiency of duct systems. For the purposes of duct efficiency calculations, the supply duct begins at the exit from the furnace or air handler cabinet.

4.8.1 Building Information and Defaults

The ACM shall use values for the parameters in Table R4-10 to calculate duct efficiencies. Standard design values and proposed design defaults are also shown. Proposed designs may claim credit for other values using the procedures in the following sections.

Table R4-10 – Duct Efficiency Input Parameters and Defaults

Parameter		Standard Design Value	Proposed Design Default
1.	Duct Location	Ducts in the attic	Ducts in the attic
2.	Insulation level of ducts	Package D requirement	Mandatory Minimum Requirement
3.	The surface area of ducts	27% of conditioned floor area (CFA) for supply duct surface area; 5% CFA for return duct surface area in single story dwellings and 10% CFA for return duct surface area in dwellings with two or more stories.	
4.	The leakage level	Sealed and tested.	Untested
5.	Fan flow	Default Cooling Airflow (Table R4-9)	
6.	Attic radiant barrier.	Yes in climate zones where required by Package D, otherwise No	No radiant barrier

When more than one HVAC system serves the building or dwelling, the HVAC distribution efficiency is determined for each system and a conditioned floor area-weighted average seasonal efficiency is determined based on the inputs for each of the systems.

See Section 3.8 for information on existing HVAC systems that are extended to serve an addition.

Diagnostic inputs may be used for the calculation of improved duct efficiency in the *Proposed Design*. The diagnostics include observation of various duct characteristics and measurement of duct leakage as described in the following sections. These observations and measurements replace those assumed as default values.

4.8.2 Duct Location

Duct location determines the external temperature for duct conduction losses, the temperature for return leaks, and the thermal regain of duct losses. Note that the area of supply ducts located in conditioned space shall be ignored in calculating conduction losses but supply duct leakage is not affected by supply duct location.

Return Duct Location

If return ducts are located entirely in the basement, the calculation shall assume basement conditions for the return duct efficiency calculation. Otherwise, the return duct shall be entirely located in the attic for the purposes of conduction and leakage calculations. Return duct surface area is not a compliance variable.

Default Supply Duct Location

Default supply duct locations shall be as shown in Table R4-11. The supply duct surface area for crawl space and basement applies only to buildings or zones with all supply ducts installed in the crawl space or basement. If the supply duct is installed in locations other than crawl space or basement, the default supply duct location shall be “Other.” For houses with 2 or more stories 35% of the default duct area may be assumed to be in conditioned space as shown in Table R4-11. The surface area of supply ducts located in conditioned space shall be ignored in calculating conduction losses. The *Standard Design* building is assumed to have the same number of stories as the *Proposed Design* for purposes of determining the duct efficiency.

Table R4-11 – Location of Default Supply Duct Area

Supply duct location	**Location of Default Supply Duct Surface Area**	
	One story	Two or more story
All in Crawl Space	100% crawl space	65% crawl space 35% conditioned space
All in Basement	100% Basement	65% basement 35% conditioned space
Other	100% attic	65% attic 35% conditioned space

DiagnosticSupply Duct Location

Supply duct location and areas other than the defaults shown in Table R4-11may be used following the procedures of 4.8.5.

4.8.3 Duct Surface Area

The supply-side and return-side duct surface areas shall be treated separately in distribution efficiency calculations. The duct surface area shall be determined using the following methods.

Return Duct Surface Area

Return duct surface area is not a compliance variable and shall be calculated using Equation R4-49.

Equation R4-49
$$A_{r,out} = K_r \times A_{floor}$$

Where K_r (return duct surface area coefficient) shall be 0.05 for one story building and 0.1 for two or more stories.

Default Supply Duct Surface Area

The standard design and default supply duct surface area shall be calculated using Equation R4-50.

Equation R4-50 $$A_{S,\,out} = 0.27 \times A_{floor} \times K_S$$

Where Ks (supply duct surface area coefficient) shall be 1 for one story building and 0.65 for two or more stories.

Supply Duct Surface Area for Less Than 12 feet of Duct Outside Conditioned Space

For proposed design HVAC systems with air handlers located outside the conditioned space but with less than 12 lineal feet of duct located outside the conditioned space including air handler and plenum, the supply duct surface area outside the conditioned space shall be calculated using Equation R4-51.

Equation R4-51 $$A_{s,out} = 0.027 \times A_{floor}$$

Diagnostic Duct Surface Area

Proposed designs may claim credit for reduced surface area using the procedures in 4.8.5.

4.8.4 Duct System Insulation

General

An air film resistance of 0.7 (h-ft²-°F/Btu) shall be added by the ACM to the insulation R-value to account for external and internal film resistance. For the purposes of conduction calculations in both the Standard and Proposed designs, 85% of the supply and return duct surface shall be assumed to be duct material at it's specified R-value and 15% shall be assumed to be air handler, plenum, connectors and other components at the mandatory minimum R-value.

Standard Design Duct Insulation R-value

Package D required duct insulation R-values shall be used in the Standard design.

Proposed Design Duct Insulation R-value

The default duct wall thermal resistance shall be the mandatory requirement. Higher insulation levels may be used in the proposed design if all the ducts outside conditioned space are insulated to this value or greater. Credit for systems with mixed insulation levels or ducts buried in the attic require the diagnostic procedure in 4.8.5.

4.8.5 Diagnostic Supply Duct Location, Surface Area and R-factor

Credit is available for supply duct systems entirely in conditioned space, with reduced surface area in unconditioned spaces and combinations of higher performance insulation. In order to claim this credit the detailed duct system design shall be documented on the plans, and the installation shall be certified by the installer and verified by a HERS rater. The size, R-value, and location of each duct segment in an unconditioned space and if buried in attic insulation, the information described below shall be shown in the design and entered into the ACM. The ACM shall calculate the area and effective R-value of the duct system in each location using the procedures specified below.

Surface Area and Location

The surface area of each supply duct system segment shall be calculated based on its inside dimensions and length. The total supply surface area in each unconditioned space location (attic, attic with radiant barrier, crawl space, basement, other) shall be the sum of the area of all duct segments in that location. The ACM shall assign duct segments located in “other” locations to the attic location for purposes of calculation. The surface area of supply ducts completely inside conditioned space need not be input in an ACM and is not included in the calculation of duct system efficiency. The area of ducts in floor cavities or vertical chases that are surrounded by conditioned space and separated from unconditioned space with draft stops are also not included.

Effective R-value

The effective R-value of a supply or return duct system constructed entirely of materials of one rated R-value shall be the rated R-value plus the film coefficient. If materials of more than one R-value are used, the area weighted effective R-value shall be calculated by the ACM using Equation R4-52 and including each segment of the duct system which has a different R-value.

Equation R4-52

$$R_{eff} = \frac{(A_1 + A_2 .... + A_N)}{\left[\frac{A_1}{R_1} + \frac{A_2}{R_2} .... + \frac{A_N}{R_N}\right]}$$

where

R_{eff} = Area weighted effective R-value of duct system for use in calculating duct efficiency,(h-ft^2-°F/Btu)

A_N = Area of duct segment n, square feet.

R_n = R-value of duct segment n including film resistance, (duct insulation rated R + 0.7), (h-ft^2-°F/Btu)

Buried Attic Ducts

Ducts partly or completely buried in blown attic insulation in dwelling units meeting the requirements for High Insulation Quality (ACM RH) and Procedures for Field Verification and Diagnostic Testing of Air Distribution Systems (ACM RC) may take credit for increased effective duct insulation using the following procedure. The duct design shall identify the segments of the duct that meet the requirements for being buried, and these shall be separately input into the ACM. Ducts to be buried shall have a minimum of R-4.2 duct insulation prior to being buried. The ACM shall calculate the correct R-value based on the specified attic insulation R-value, insulation type, and duct size for ducts installed on the ceiling, and whether the installation meets the requirements for deeply buried ducts for duct segments buried in lowered areas of ceiling. Correct installation of the duct system and attic insulation shall be certified by the installer and verified by a certified HERS rater (including that the requirements of ACM RH and ACM RC are met).

Buried Ducts on the Ceiling

The portions of duct runs directly on or within 3.5 inches of the ceiling gypsum board and surrounded with blown attic insulation of R-30 or greater may take credit for increased effective duct insulation as shown in Table R4-12. Credit shall be allowed for buried ducts on the ceiling only in areas where the ceiling is level and there is at least 6 inches of space between the outer jacket of the installed duct and the roof sheathing above.

Deeply Buried Ducts

Duct segments deeply buried in lowered areas of ceiling and covered by at least 3.5” of insulation above the top of the duct insulation jacket may claim effective insulation of R-25 for fiberglass insulation and R-31 for cellulose insulation.

Table R4-12 – Buried Duct Effective R-values

	Nominal Round Duct Diameter								
Attic Insulation	4"	5"	6"	7"	8"	10"	12"	14"	16"
	Effective Duct Insulation R-value for Blown Fiberglass Insulation								
R-30	R-13	R-13	R-13	R-9	R-9	R-4.2	R-4.2	R-4.2	R-4.2
R-38	R-25	R-25	R-25	R-13	R-13	R-9	R-9	R-4.2	R-4.2
R-40	R-25	R-25	R-25	R-25	R-13	R-13	R-9	R-9	R-4.2
R-43	R-25	R-25	R-25	R-25	R-25	R-13	R-9	R-9	R-4.2
R-49	R-25	R-25	R-25	R-25	R-25	R-25	R-13	R-13	R-9
R-60	R-25	R-25	R-25	R-25	R-25	R-25	R-25	R-25	R-13
	Effective Duct Insulation R-value for Blown Cellulose Insulation								
R-30	R-9	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2
R-38	R-15	R-15	R-9	R-9	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2
R-40	R-15	R-15	R-15	R-9	R-9	R-4.2	R-4.2	R-4.2	R-4.2
R-43	R-15	R-15	R-15	R-15	R-9	R-4.2	R-4.2	R-4.2	R-4.2
R-49	R-31	R-31	R-15	R-15	R-15	R-9	R-9	R-4.2	R-4.2
R-60	R-31	R-31	R-31	R-31	R-31	R-15	R-15	R-9	R-9

4.8.6 Fan Flow

Default System Fan Flow

The default fan flow for an air conditioner and for heating with a heat pump in all climate zones shall be obtained from Table R4-9.

The default heating fan flow for forced air furnaces for all climate zones shall be calculated as follows:

Equation R4-53 $$Q_e = 0.50 \times A_{floor}$$

4.8.7 Duct Leakage

Duct leakage factors shown in Table R4-13 shall be used in calculations of delivery effectiveness. Table R4-13 shows default duct leakage factors for dwelling units. Sealed and tested duct systems require the diagnostic leakage test by the installer and verification by a HERS rater meeting the criteria described in ACM RC-2005. The duct leakage factors for sealed and tested new duct systems correspond to sealed duct requirements in newly constructed dwelling units, to entirely new duct systems in existing dwelling units, and to duct systems in alterations and additions that have been sealed to meet the duct leakage requirements of newly constructed buildings. The duct leakage factors for sealed and tested duct systems in existing dwelling units apply only to sealed duct requirements for alterations to existing dwelling units and to extensions of existing duct systems to serve additions. See Section 3.8 for ducts in existing dwelling units that are sealed and tested in conjunction with alterations or additions.

Table R4-13 – Duct Leakage Factors

Case	$a_s = a_r =$
Untested duct systems in homes built prior to June 1, 2001	0.86
Untested duct systems in homes built after June 1, 2001	0.89
Sealed and tested duct systems in existing dwelling units	0.915
Sealed and tested new duct systems	0.96

4.8.8 Seasonal Distribution System Efficiency

ACMs shall use the following algorithms to calculate duct and HVAC distribution efficiency.

The seasonal distribution system efficiency shall be calculated separately for the heating and cooling seasons using Equation R4-54 based on the seasonal delivery effectiveness from Equation R4-55 and the recovery factor from Equation R4-64. Note that $DE_{seasonal}$, F_{recov} shall be calculated separately for cooling and heating seasons. Distribution system efficiency shall be determined using the following equation:

Equation R4-54

$$?_{dist,seasonal} = 0.98\, DE_{seasonal} \times F_{recov}$$

where 0.98 accounts for the energy losses from heating and cooling the duct thermal mass. F_{recov} is calculated in Equation R4-64.

4.8.9 Seasonal Delivery Effectiveness

The seasonal delivery effectiveness for heating or cooling systems shall be calculated using Equation R4-55. This value shall be calculated separately for the heating season and the cooling season.

Equation R4-55

$$DE_{seasonal} = a_s B_s - a_s B_s (1 - B_r a_r) \frac{\Delta T_r}{\Delta T_e} - a_s (1 - B_s) \frac{\Delta T_s}{\Delta T_e}$$

where

B_s = Conduction fraction for supply as calculated in Equation R4-56.

B_r = Conduction fraction for return as calculated in Equation R4-57.

ΔT_e = Temperature rise across heat exchanger, ºF. This value changes for heating and cooling modes.

ΔT_r = Temperature difference between indoors and the ambient for the return, ºF. This value changes for heating and cooling modes.

ΔT_s = Temperature difference between indoors and the ambient for the supply, ºF. This value changes for heating and cooling modes.

a_r = Duct leakage factor (1-return leakage) for return ducts. A value is selected from Table R4-13

a_s = Duct leakage factor (1-supply leakage)p for supply ducts. A value is selected from Table R4-13

Equation R4-56

$$B_s = \exp\left(\frac{-A_{s,out}}{1.08 Q_e \times R_s}\right)$$

Equation R4-57

$$B_r = \exp\left(\frac{-A_{r,out}}{1.08Q_e \times R_r}\right)$$

where

$A_{s,out}$ = Surface area of supply duct outside conditioned space, ft². See Sections 4.8.1, 4.8.2 and 4.8.3.

$A_{r,out}$ = Surface area of return duct outside conditioned space, ft^2. See Sections 4.8.1, 4.8.2 and 4.8.3.

Q_e = Flow through air handler fan at operating conditions, cfm. This is determined from Section 4.7.4.

R_r = The effective thermal resistance of return duct, h ft^2 F/Btu. See Section 4.8.4 and 4.8.5.

R_s = The effective thermal resistance of supply duct, h ft^2 F/Btu. See Section 4.8.4 and 4.8.5.

4.8.10 Climate and Duct Ambient Conditions for Ducts Outside Conditioned Space

Duct ambient temperature for both heating and cooling for different duct locations shall be obtained from Table R4-14. Attic temperatures for houses with radiant barriers also shall be obtained from Table R4-14. Reduction of attic temperature and the reduction in solar radiation effect due to radiant barriers shall only be applied to cooling calculations. The eligibility criteria for radiant barriers is given in Section 4.2.1. Indoor dry-bulb (T_{in}) temperature for cooling is 78°F. The indoor dry-bulb temperature for heating is 70°F.

Table R4-14 – Assumptions for Duct Ambient Temperature (ºF)

Climate zone	Ambient Temperature for Heating, $T_{heat,amb}$ Attic	Crawl Space	Basement	Ambient Temperature for Cooling, $T_{cool,amb}$ Attic	Attic w/ radiant barrier (supply)	Attic w/ radiant barrier (return)	Crawl Space	Basement
1	52.0	52.2	48.9	60.0	65.4	61.2	54.0	49.1
2	48.0	48.7	56.5	87.0	84.3	84.2	78.0	64.5
3	55.0	54.9	58.3	80.0	79.4	78.2	71.8	62.8
4	53.0	53.1	56.6	79.0	78.7	77.4	70.9	61.4
5	49.0	49.6	52.3	74.0	75.2	73.1	66.4	56.8
6	57.0	56.7	59.9	81.0	80.1	79.1	72.7	64.1
7	62.0	61.1	60.4	74.0	75.2	73.1	66.4	61.6
8	58.0	57.6	60.1	80.0	79.4	78.2	71.8	63.9
9	53.0	53.1	59.6	87.0	84.3	84.2	78.0	66.4
10	53.0	53.1	61.1	91.0	87.1	87.6	81.6	68.9
11	48.0	48.7	59.5	95.0	89.9	91.0	85.1	69.5
12	50.0	50.4	59.3	91.0	87.1	87.6	81.6	67.8
13	48.0	48.7	58.4	92.0	87.8	88.4	82.4	67.6
14	39.0	40.7	55.4	99.0	92.7	94.4	88.7	68.6
15	50.0	50.4	63.4	102.	94.8	96.9	91.3	74.6
16	32.0	34.4	43.9	80.0	79.4	78.2	71.8	54.1

4.8.11 Calculation of Duct Zone Temperatures for Multiple Locations

The temperatures of the duct zones outside the conditioned space are determined in Table R4-14 for seasonal conditions for both heating and cooling. If the ducts are not all in the same location, the duct ambient temperature for use in the delivery effectiveness and distribution system efficiency calculations shall be determined using an area weighted average of the duct zone temperatures.

Equation R4-58

$$T_{amb,s} = \frac{(A_{s,attic} + 0.001)T_{attic} + A_{s,crawl} \times T_{crawl} + A_{s,base} \times T_{base}}{A_{s,out}}$$

Equation R4-59

$$T_{amb,r} = \frac{A_{r,attic}\ T_{attic} + A_{r,crawl} \times T_{crawl} + A_{r,base} \times T_{base}}{A_{r,out}}$$

The return ambient temperature, $T_{amb,r}$, shall be limited as follows:

- For heating, the maximum $T_{amb,r}$ is $T_{in,heat}$.
- For cooling, the minimum $T_{amb,r}$ is $T_{in,cool}$.

4.8.12 Temperature Difference Across Heat Exchanger

The temperature difference across the heat exchanger is determined by Equation R4-60:

For heating:

Equation R4-60 $$\Delta T_e = 55$$

And Equation R4-61 for cooling:

Equation R4-61 $$\Delta T_e = -20$$

4.8.13 Indoor to Duct Location Temperature Differences

The temperature difference between the building conditioned space and the ambient temperature surrounding the supply, ΔT_s, and return, ΔT_r, shall be calculated using the indoor and the duct ambient temperatures.

Equation R4-62 $$\Delta T_s = T_{in} - T_{amb,s}$$

Equation R4-63 $$\Delta T_r = T_{in} - T_{amb,r}$$

4.8.14 Thermal Regain (F_{regain})

The reduction in building load due to regain of duct losses shall be calculated using the thermal regain factor. The thermal regain factors that are required to be used are provided in Table R4-15.

Table R4-15 – Thermal Regain Factors

Supply Duct Location	Thermal Regain Factor [F_{regain}]
Attic	0.10
Crawl Space	0.12
Basement	0.30
Other	0.10

4.8.15 Recovery Factor (F_{recov})

The recovery factor, F_{recov}, shall be calculated based on the thermal regain factor, F_{regain}, and the duct losses without return leakage.

Equation R4-64 $$F_{recov} = 1 + F_{regain}\left(\frac{1 - a_S B_S + a_S B_S (1 - B_r)\frac{\Delta T_r}{\Delta T_e} + a_S (1 - B_S)\frac{\Delta T_S}{\Delta T_e}}{DE_{seasonal}}\right)$$

4.9 Hourly Attic Duct Efficiency Multipliers

The algorithm in this section shall be used to model the hourly variation in duct efficiency for ducts located in attics. No hourly variation is modeled for ducts located in spaces other than attics. The multipliers are determined as described in Section 4.9.1 below:

4.9.1 Hourly Duct Efficiency Multipliers

The hourly duct efficiency multiplier for ducts in attics shall be calculated for each hour using Equation R4-65 through Equation R4-68.

Equation R4-65
$$DEM_{hr} = 1 + C_{DT} \times \left(\frac{\Delta T_{sol,hr}}{?T_{sol,season}} - 1 \right)$$

Equation R4-66
$$\Delta T_{sol,hr} = T_{solair,hr} - T_{in,hr}$$

Equation R4-67
$$T_{solair,hr} = T_{amb,hr} + \left(\frac{a}{h_o} \right) \times I_{hor,hr} - ?T_{sky}$$

Equation R4-68
$$C_{DT} = C_0 + {}^{C_R}\!/\!_{R_{duct}} + C_L L_{duct}$$

where

DEM_{hr} =	The hourly duct efficiency multiplier for ducts located in all locations. This value is calculated for each hour and separately for the heating season ($HDEM_{hr}$) and cooling season ($CDEM_{hr}$).
$T_{solair,\ hr}$	Sol-air temperature, ºF. See Equation R4-67.
$T_{in,hr}$	Indoor air dry-bulb temperature from simulation, °F.
$T_{amb,hr}$	Outdoor air dry-bulb temperature, °F. From the CEC weather file.
ΔT_{sky}	Reduction of sol-air temperature due to sky radiation, = 6.5 ºF.
$I_{hor,hr}$	Global solar radiation on horizontal surface, Btu/h-ft². From the CEC weather file.
α	Solar absorptivity of roof = 0.50.
h_o	Outside surface convection coefficient, = 3.42 Btu/h-ft²-ºF.
$\Delta T_{sol,\ season}$	Energy weighted seasonal average difference between sol-air and indoor temperatures. This is taken from Table R4-17.
R_{duct}	Duct insulation R-value, hr ft^2°F/Btu.
L_{duct}	Duct leakage as fraction of supply airflow, dimensionless. See Table R4-13.
C_{DT}, C_0, C_R, C_L	Regression coefficients. See Table R4-16.

Table R4-16 – Regression Coefficients

		Cooling		Heating	
		Radiant Barrier	No Radiant Barrier	Radiant Barrier	No Radiant Barrier
C_0	(Unitless)	0.0078	0.0186	0.0350	0.0205
C_R	(h-ft²-ºF/Btu)	0.1222	0.0877	0.0794	0.1202
C_L	(Unitless)	0.5480	0.2995	0.0714	0.2655

Table R4-17 – Seasonal Sol-Air Temperature Difference, °F

Climate Zone	Cooling	Heating
1	23.00	-20.01
2	31.69	-23.64
3	23.66	-18.90
4	26.29	-21.13
5	26.02	-20.25
6	23.79	-17.12
7	25.17	-17.16
8	30.89	-19.46
9	32.73	-18.85
10	33.34	-21.53
11	34.24	-24.38
12	34.65	-23.31
13	34.53	-22.92
14	35.29	-25.64
15	33.33	-20.32
16	29.43	-29.86

4.10 Water Heating Calculations

The water heating budget is the TDV energy that would be used by a system that meets the requirements of the standards (see Section 3.7 for details). The calculation procedure is documented in ACM RG-2005.